

Modelling Drell-Yan pair production in $\bar{p}p$ ¹

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Abstract. We predict the triple differential cross section of the unpolarized Drell-Yan process at $\sqrt{S} = 6$ GeV. The model incorporates primordial parton transverse momentum and quark off-shellness effects caused by the initial state interaction.

The study of the Drell-Yan lepton pair production process ($NN \rightarrow \mu^+ \mu^- X$) improves our understanding of the quark-gluon structure of the nucleon. It provided the most accurate data on the sea quark distribution in the nucleon and also additionally constrained the valence quark distributions earlier measured in deep inelastic scattering. The PANDA [1] experiment at the future GSI facility will use the $\bar{p}p \rightarrow \mu^+ \mu^- X$ reaction to pin down the polarized quark distributions in the proton.

The conventional perturbative QCD (pQCD) approach to the calculation of hard scattering cross sections assumes that the partons in hadrons are collinear and on-shell. This is equivalent to using the impulse approximation, *i.e.* neglecting the initial and finite state interactions (ISI and FSI). Next to leading order pQCD calculations reproduce the Drell-Yan cross section integrated over the transverse momentum of the lepton pair (p_T). However, it fails to reproduce the un-integrated triple differential cross section. A number of effects missed in the standard perturbative treatment are essential to explain the observed p_T -spectrum of the lepton pairs. Namely,

- the interaction of the active quark with the spectators,
- intrinsic transverse momentum of partons (k_T),
- soft gluon radiation.

Nonperturbative effects are especially sizable at low \sqrt{S} and high ratios M^2/S , where M is the mass of Drell-Yan pair, which is exactly the kinematical region to be probed by PANDA. The aforesaid effects can not be described in any fixed order of the perturbative expansion and require a resummation of an infinite number of diagrams and modelling of the non-perturbative higher twist contributions.

We have parametrized the effects listed above by means of k_T -unintegrated parton distributions and a phenomenological spectral function for (anti-) quarks in the nucleon. The non-vanishing intrinsic transverse momentum k_T and the off-shellness $m^2 \equiv k^+ k^- - k_T^2$ of the partons are generated by the ISI. The off-shellness distribution is taken as a

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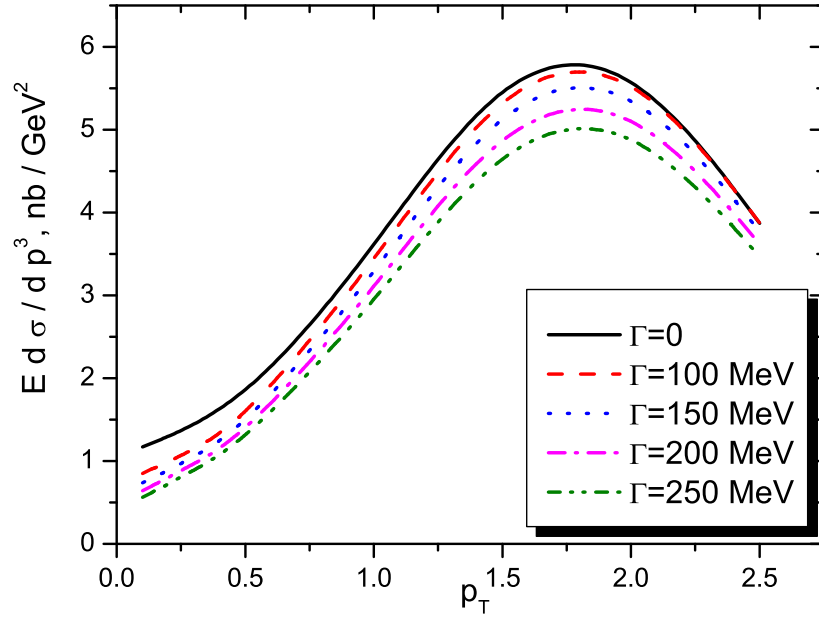


FIGURE 1. Prediction for the p_T -distribution of Drell-Yan lepton pairs in $\bar{p}p$ collision at $\sqrt{S} = 6$ GeV, $M = 1$ GeV. Average quark intrinsic transverse momentum is 1 GeV. The solid line is the result of calculations in the intrinsic- k_T approach (width $\Gamma = 0$). The other curves are generated with Γ in the range determined by fitting existing Drell-Yan data. $x_F = 0.1$ in all plots.

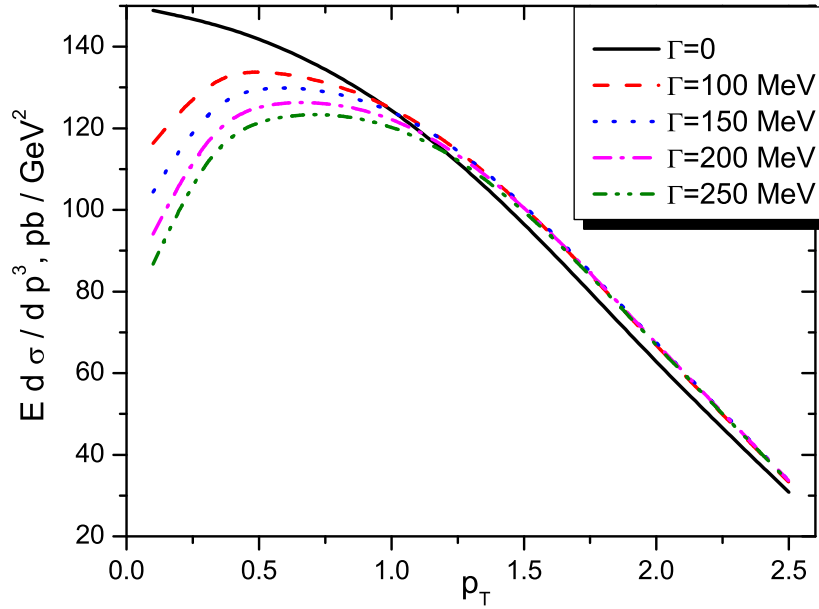


FIGURE 2. Same as Fig. 1, but for the Drell-Yan pair mass $M = 2$ GeV.

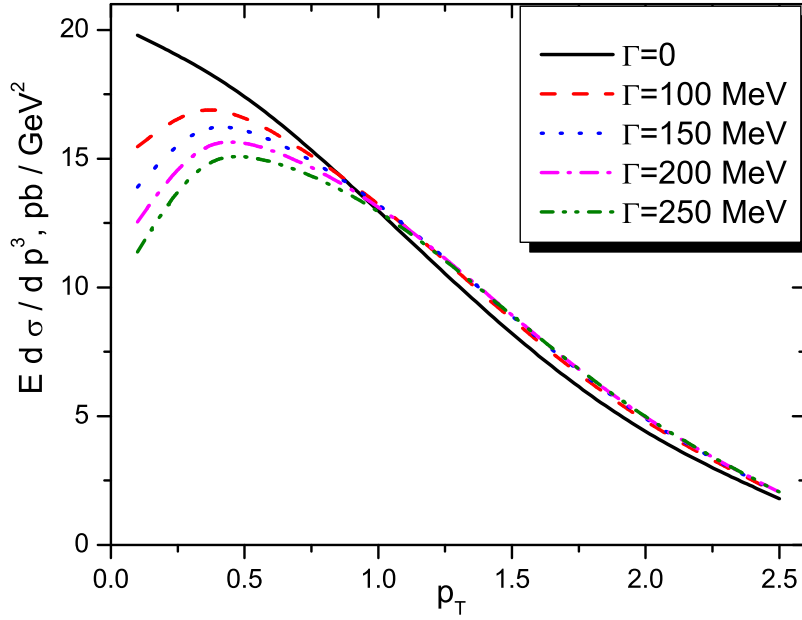


FIGURE 3. Same as Fig. 1, but for the Drell-Yan pair mass $M = 3$ GeV.

Breit-Wigner in m with a constant width Γ :

$$A(m, \Gamma) = \frac{1}{\pi} \frac{\Gamma}{m^2 + \frac{1}{4}\Gamma^2}. \quad (1)$$

Additionally, we take into account the exact off-shell kinematics. The model was developed in [2], where it was applied to calculate the ISI effects in deep inelastic scattering (DIS) and the Drell-Yan process.

The calculations in this approach are in excellent agreement with Drell-Yan data from Fermilab at projectile energies of 800 GeV/c and 125 GeV/c [2]. The p_T -distribution of the lepton pairs $d\sigma/dM^2 dp_T^2 dx_F$ was reproduced as well as the partly integrated (double-differential) cross sections. Here, x_F is the Feynman variable of the produced lepton pair. Both shape and magnitude of the observed triple differential cross sections were reproduced very well in all the bins of M , x_F and p_T without a need for a K-factor.

The success of our description of the data over the wide range of \sqrt{s} allowed us to extrapolate the values of the two model parameters (k_T dispersion and the quark width) to $\sqrt{s} = 6$ GeV and $M < 6$ GeV. In this contribution, we present a prediction for the triple differential Drell-Yan cross section in the kinematical region of this low \sqrt{s} and high ratio M/\sqrt{s} .

The prediction for the transverse momentum distribution of the Drell-Yan pairs at $\sqrt{s} = 6$ GeV is presented in Fig. 1-4 for different masses of the produces pairs. We have plotted the observable

$$\frac{d\sigma}{d\vec{p}} \equiv \frac{2}{\pi\sqrt{s}} \frac{d\sigma}{dx_F dp_T^2} = \frac{2}{\pi\sqrt{s}} \int_{\text{bin}} \frac{d\sigma}{dx_F dp_T^2 dM^2} dM^2 \quad (2)$$

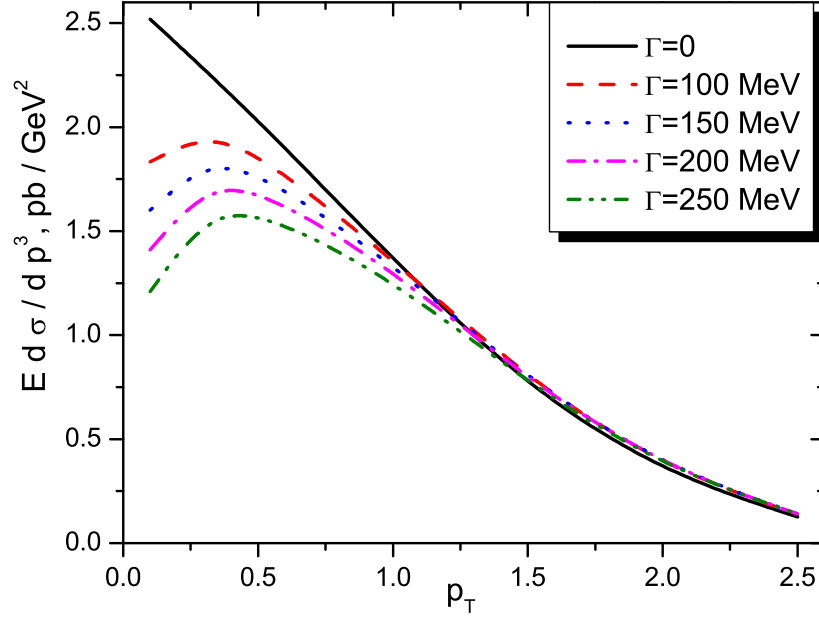


FIGURE 4. Same as Fig. 1, but for the Drell-Yan pair mass $M = 5$ GeV.

for $M = 1, 2, 3, 5$ GeV. The plot for $M = 4$ GeV is not shown, because the Drell-Yan process in this region can not be experimentally disentangled from the charmonium production. Note that the scale changes from nb in Fig. 1 to pb in the other figures. Note also the qualitative difference of the cross section at the Drell-Yan pair mass $M = 1$ GeV from the other plots. In contrast to the higher mass bins, the peak of the p_T -distribution in Fig. 1 is not around zero. This behavior appears, when M approaches the partonic average intrinsic transverse momentum, *i.e.* in the distribution of the low virtuality photons, which can be produced by the partonic transverse motion alone. It is worthwhile to stress that this drastic change in the p_T -dependence of the cross section takes place for all values of Γ . An experimental verification of this effect would be a direct test for the transverse momentum distribution of quarks in the proton.

We have generated several theoretical curves with $\Gamma = (100 - 250)$ MeV, which is the range determined from fitting the Drell-Yan data at higher energies. The solid lines are the results of our calculations in the intrinsic- k_T approach ($\Gamma = 0$) [2]. The uncertainty of Γ reflects the lack of data in the low \sqrt{S} region. We expect that PANDA data will allow us to constrain the quark spectral function in the proton with a much better accuracy (see [3] for details).

REFERENCES

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